TOPEX/Poseidon Orbit Maintenance for First Five Years*

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Since its launch on August 10, 1992, the TOPEX/Poseidon, a joint lJS/French mission, has been precisely mapping earth ocean topography. It has mapped over 95% of the icc-free seas and provided a wealth of information to scientists during five years of operations. These five years include three years of primary and two years of extended mission operations. The very high quality of ocean-altimetry data provided by the satellite prompted the National Aeronautics and Space Administration(NASA) and the French space agency, Centre National d'Etudes Spatiales(CNES) to continue mission operations further through the year 2001 phase to overlap with the follow-on Jason(French/US) mission.

Prior to launch, the TOPEX/Poseidon orbit maintenance maneuver(OMM) design was expected to depend primarily on atmospheric drag and uncertainties of its prediction. The maneuver targeting strategy had to be changed following launch duc to the observation of unexpected along-track forces called "anomalous forces". The magnitude of these anomalous forces is equivalent to or greater than the effects of the atmospheric drag and causes orbital boost or decay depending on the satellite attitude mode and solar array orientation. A passive maneuver technique was evolved using this anomalous force and it has been effectively used for orbit maintenance to reduce the number of propulsive maneuvers. Thus, the TOPEX/Poseidon orbit has been maintained, in a unique way, using both passive and active(propulsive maneuvers) techniques. in fact, the orbit has been maintained using only passive techniques since 0MM9 on January 15, 1996. Use of these passive techniques has cased the mission operations.

This paper describes the maneuver design and implementation strategies used for orbit maintenance in presence of the anomalous force during the five years of operations. The maneuver performance characteristics including ground track maintenance statistics arc provided. Use of passive techniques in reducing the nurnber of maneuvers and complexity of the mission operations arc summarized.

Only nine OMMS have been implemented to maintain ground track and verification site overflights since achieving the operational orbit on September 21, 1992. All maneuvers have been designed and implemented consistent with the mission requirements and operational constraints. All maneuvers have met the performance requirements except 0MM9. Maneuver magnitudes arc in the range of 2-5 mm/sec duc to prevailing low drag and solar activity conditions. This paper will illustrate the usc of the passive technique by summarizing the strategy used to remove the excess AV, following 0MM9, duc to unexpected altitude thruster firings during "unwind" turn after the burn,

To facilitate high quality altimetry data acquisition, the satellite is maintained in a nearly-circular, frozen orbit ($e = 0.000095, \omega = 90^{o}$) at an altitude of =1336 km and an inclination of i = 66.04°. This orbit provides an exact repeat ground track every 127 orbits (=1() days) and overflies two verification

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sites: a NASA silt off lhc coast of Point Conception and a CNES site near lhc islands of Lampionc and Lampcdusa in the Mcditcrrancan Sea. The scicncc objectives require that 95% of all equatorial crossings be controlled within ±1 km about a prc-defined earth-fixed rcfcrcncc ground track grid, and that 95% of all verification site overflights have a miss distance at c1oscs[approach of ±1 km during the first six months. However, this rcquircmcnl cxlcndcd throughout the operational phase, and continues even during cxlcndcd operations. The OMMS arc constrained to occur over land at near the boundary of ground track repeat cyclcs(±1 orbit). Maneuver spacing must be as large as practical with a minimum spacing of 30 days. Eccentricity must be maintained less than ().001 throughout the mission.

The Jct Propulsion Laboratory (JPL) is responsible for conducting all mission operations including operational navigation. Operational orbit dctcrminalion using radiomctric data acquired via the NASA Tracking Data Relay Satellite Systcm(TDRSS) is provide.d by the Flight Dynamics Facility(FDF) of NASA's Goddard Space Flight Ccntcr(GSFC). The accuracy of orbit determination results provided by lhc FDF have been better than lhc rcqui rcmcnls speci ficd prior to lhc launch.

Although TOPEX/Poseidon is a three-axis stabilized satcllitc, near-continuous yaw steering and solar array-pitching points the solar panel sunward and a pitch bias is applied to lhc solar panel to avoid battery overcharging. The satellite nominally flies with the solar panel in a "Lead" position(positivc pitch bias). To avoid cxccssivc yaw ratcs, the satellite yaw anglc is held fixed when $-15^o \le \beta' \le 15^o$, where β' is lhc angle bctwccn the orbital plane and carlh-sun line. Two different fixed yaw angles arc used: yaw = O" satellite when $0^o \le \beta' \le 15^o$ *(flying forward)*, and yaw = 180" when $-15° \le \beta' < 0^o$ *(flying backward)*. The satellite is continuous] y yaw stccrcd for all other values of ß´. When $\beta' > 15^o$ this is rcfcrrcd to as *positive yaw steering* , and when $\beta' < -15°$ it is rcfcrrcd to as *negative yaw steering.*

The anomalous force causes orbital boost(increascs scmi-major axis) during negative yaw stccring and causes dccay(dccrcascs semi-major axis) during positive yaw stccring. The orbital boost when the satellite is *flying forward* and the decay during *flying backward* is 3-5 times grcalcr than the decay caused by the atmospheric drag during the solar minimum. Additional orbital boost or decay is applied by varying fixed yaw pcriods and reversing solar army oricntation(Lcad to Lag) during appropriatc timcs during the fixed yaw period. This passive tcchniquc(non propulsive) is now operationally used to control the ground track and is called "1. cad/Lag" strategy.

As of August 18, 1997, TOPEX/Poseidon had completed 181 ground track rcpcat cycles in the operational orbit. Only 95 out of 23,932 equatorial crossings have been outside the control band of ±1 km, comfortably meeting the mission rcquircmcnt(95%). Even thcsc 95 violations were voluntary and occurred very early in lhc mission as OMM 1 was intentionally delayed to allow time to understand the anomalous force. Similarly, maintenance of the NASA and CNES vcrification site overflights has easily surpassed the mission rcquircmcnt. The CNES site was closcd on February 1, 1997 and only the NASA sitc overflight requirement continues during the extended operations.

The value of scmimajor axis varies within 7 mctcrs about the rcfcrcncc value of 7714.429 km. Periodic fluctuations in inclination arc within 3.8 mdcg about lhc rcfcrcncc valuc(66.0408 dcg). The mission rcquircmcnt to keep lhc cccentricity within 0.001 has been easily mct without implementing any dedicated eccentricity maneuvers. The frozen cccentricity vector has complctcd two periodic cycles and it is currently tracing the third cyclc(pcriod = 26.7 months)

The orbit is currently being maintained using only passive techniques since 0MM9 on January 1996. These passive techniques were used to achicvc lhc conditions required for TOPEX Autonomous Maneuver Expcrimcnt(TAME) schcdulcd on Dcccmbcr 19, 1997. Howcvcr, TAME has been postponed by the Project, but these techniques will continue to maintain ground track within ±1 km as long as practically possible. The paper will include brief description on strategies used to achieve lhc prc-TAME conditions and it will also provide highlights on the currcnt status of orbit and ground track maintenance.